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PULSE MEASUREMENT TECHNIQUES FOR THE STUDY OF SECONDARY ELECTRON-EMISSION PROPERTIES OF INSULATORS

by

A. B. Laponsky and N. R. Whetten

Report No. 56-RL-1660 November 1956

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ABSTRACT

Single pulse measurement methods and surface potential stabilization methods for secondary electron-emission studies of insulators are discussed. The possibility is indicated of extending secondary electron-emission studies of insulators to materials as yet not extensively investigated because of difficulties due to charging and bombardment damage. The advantages in higher sensitivity of measuring charge rather than current are demonstrated. A total bombarding charge of 10^{-14} coulombs per measurement has been readily obtained. Three techniques for returning the insulator to the original surface potential after each measurement are compared. The heating method and the low energy bombardment method are found to agree to within the experimental error in studies on single crystals of MgO.

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INTRODUCTION

Secondary electron-emission studies of insulators must contend with problems not encountered with conductors. The surface of an insulator may charge during the measurements. For many investigations, such as the determination of the energy distribution of the secondaries, charging of the surface may seriously limit the resolution obtainable. Some insulators damage readily under electron bombardment, so that a minimum of bombardment must be used. Finally, for many studies the surface must be reliably returned to the original potential after each measurement. This report describes methods of measurement that the authors have found to be valuable in determining the secondary electron-emission characteristics of insulators.[1] The first part of the report describes a method of pulse measurements that is capable of considerably reducing charging and bombardment damage of the insulator. The method is a modification of pulse techniques such as employed by Johnson and McKay, and others.[2-9] The latter part of this report is concerned with returning the insulator surface to the original potential after each measurement. Three procedures for accomplishing this are compared.

PART I: PULSE MEASUREMENT TECHNIQUES

CHARGING

Since the current incident on a target surface is seldom equal to the current leaving the surface, the surface will charge. For many measurements such as determining the energy distribution of the secondaries, charging of the surface must be reduced as much as possible.

The change in potential of the target surface is dependent upon the following factors: (1) secondary emission ratio, (2) target resistivity and dielectric constant, (3) target thickness, (4) primary current density, and (5) time required for measurements. The first two are intrinsic properties of the material being investigated. The last three are to some extent adjustable. The potential change due to charging can be decreased by reducing the target thickness. For bulk insulators such as cleaved single crystals this is limited by the thickness to which the crystal can be cleaved. Reduction of current density may be achieved by decreasing the bombarding current and increasing the sensitivity of the measuring equipment, but may be limited by noise. Increasing the electron beam diameter also reduces the current density. Reduction in the time necessary to make measurements reduces accumulation of charge and has led to the use of pulse methods. Pulse methods offer an opportunity to overcome the effects of cumulative charging by utilizing the period between pulses to establish the target surface potential at a known reproducible value.

PULSE METHODS

Single pulse techniques[2-9] have been used to reduce the number of electrons incident on the target per measurement. Figure 1 shows a schematic arrangement of the measuring tube and associated circuits for secondary emission studies. The tube includes an electron gun, a collector for the secondary electrons, and an insulating target mounted on a conducting substrate. The use of an auxiliary filament and substrate heater for establishing target surface potentials will be described in Part II.

A single pulse from the pulse generator results in a burst of primary current to the target. When the collector is sufficiently negative with respect to the target surface, the primary electron current can be determined from the current in the target circuit. Similarly positive

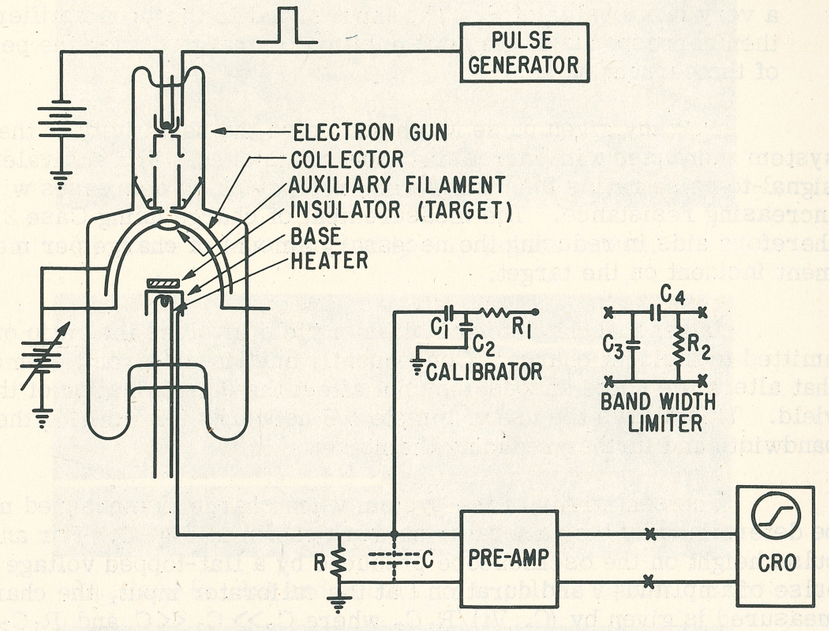


Fig. 1 Schematic diagram of measuring tube and associated circuits. For Case 1 (current method), R = 2000 ohms. For Case 2 (charge method), R = 5×10^7 ohms. Typical values used for calibrator and bandwidth limiter are: $C_1 = 1.0\ \mu\mu f$, $C_2 = 0.01\ \mu f$, $R_1 = 10$ K, $C_3 = 0.03\ \mu f$, $C_4 = 100\ \mu\mu f$ and $R_2 = 100$ K.

values of the collector potential enable the difference between secondary and primary currents to be determined. The potential waveforms at the input to the preamplifier are displayed on an oscilloscope and photographed. The pulse heights from which the yield is calculated are measured from the photographs. The following two cases can be distinguished.

Case 1 - Assume that the RC time constant of the input circuit is small compared to the primary current pulse duration. This is essentially the method used by most workers and results in the detection of current. The current in the target circuit is reproduced as a voltage across the input resistor (and instantaneous charge across the input capacitance).

Case 2 - Assume that the input RC time constant is much larger than the primary current pulse duration. This is achieved by using a very large value of R. The input signal to the preamplifier then corresponds to the accumulation of charge during the period of the current pulse.[10]

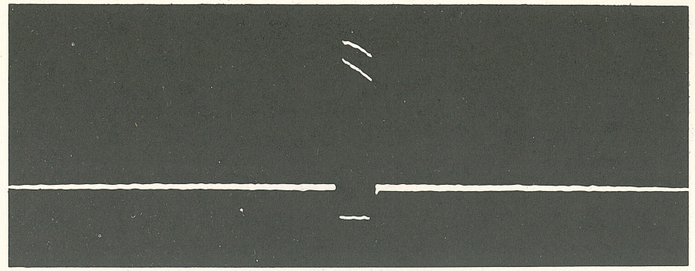
For any given pulse width and noise the sensitivity of the system increases with increasing input resistance. For equivalent signal-to-noise ratios the charge required per pulse decreases with increasing resistance. The measurement of charge using Case 2 therefore aids in reducing the necessary amount of charge per measurement incident on the target.

In general the determination of yield involves the ratio of the emitted to incident charge. Consequently any linear circuit element that alters the pulse shapes does not affect the determination of the yield. This allows the use of simple RC networks for limiting the bandwidth and further reducing the noise.

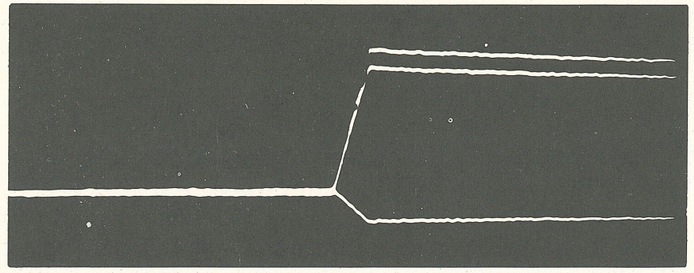
The sensitivity of the system when charge is measured may be determined by the calibrator network shown in Fig. 1. For any given pulse height on the oscilloscope produced by a flat-topped voltage pulse of amplitude V and duration t at the calibrator input, the charge measured is given by $(C_1\ Vt)/R_1C_2$ where $C_2 \gg C_1 \ll C$ and $R_1C_2 \gg t \ll RC$.

EXPERIMENTAL PULSE COMPARISIONS

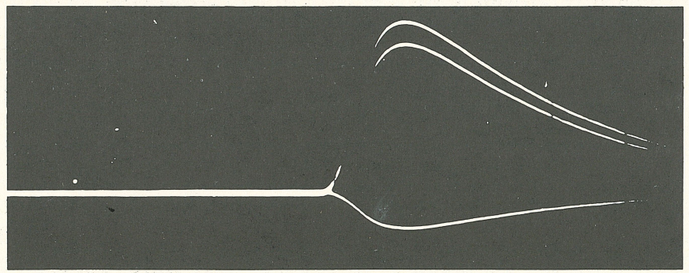
Secondary emission measurements have been obtained using the system depicted in Fig. 1, employing 3 microsecond flat-topped pulses, a 3-tube model 100 preamplifier,[11] and a Tektronix type 513-D oscilloscope. Typical pulse shapes are shown in Fig. 2. These were all obtained using a single crystal of MgO. Figure 2(a) shows pulse forms obtained under the conditions of Case 1. A 2000-ohm input resistor was used and the system bandwidth was about 4 megacycles. The downward pulse corresponds to the primary current while the upward pulses correspond to the 1st and 2nd pulses of net electron flow from the target. The decay in the pulse heights with time and the lack of recovery between pulses is an indication of charging. Figure 2(b) shows pulse forms obtained under conditions of Case 2 in which charge was detected. An input resistance of 5×10^7 ohms was employed. The amplifier gain was decreased to give approximately the same noise as in Fig. 2(a). The downward pulse corresponds to the total primary charge incident on the target during the 3 microsecond current pulse.



(a) Case 1. 1st and 2nd $i_2 - i_1$ pulses shown.



(b) Case 2. 1st and 128th $i_2 - i_1$ pulses shown.



(c) Case 2. Reduced bandwidth showing 1st and 128th $i_2 - i_1$ pulses.

Fig. 2 Oscilloscope traces of secondary and primary pulses. Upward pulses correspond to $i_2 - i_1$. Downward pulses correspond to i_1.

The upward pulses correspond to the net charge leaving the target during this interval. The upward pulses show the 1st and 128th pulses of the electron beam. The decay in yield due to charging during these 128 pulses is roughly the same as that during a single pulse of the current measuring method. The improvement was possible because of higher sensitivity of the system under conditions of Case 2 and shows how effectively charging has been minimized. In order to reduce noise, the bandwidth of the system was limited to the spectrum between 10 kc and 120 kc by the network composed of R_2, C_3 and C_4. Figure 2(c) shows pulse forms for the system with reduced bandwidth. The noise has been considerably reduced. Again the pulses are proportional to the primary charge and the net charge leaving the target during the 1st and 128th pulses. The system sensitivity for Figs. 2(b) and (c) was in both cases about 10^{-14} coulombs/cm pulse height. The downward pulses are 0.5 cm high.

DISCUSSION

The charge method of Case 2 greatly reduces the number of primary electrons necessary per measurement. It is difficult to make a direct comparison of the ultimate possibilities of the two methods, since the pulse width in the current method (Case 1) may be made very small. However noise considerations may then become severe. The system sensitivity using the charge method of 10^{-14} coulombs/cm pulse height was readily obtained with a 30:1 signal-to-noise ratio.

It should be pointed out that care must be taken when measuring total yield that the target does not charge to the collector potential during the pulse, causing secondaries to return to the target. The existence of this condition is less obvious than when observing flat-topped pulses with the current method. Pulse height ratios may be measured at several places along the trace and compared to check this condition, or successive pulses may be compared without intervening stabilization. Similarly, care should be taken to ascertain that time-delayed emission (Malter effect)[12] is not present.

The charge method has proven to be useful under conditions where charging of the insulator is severe as with high yield bulk crystals, and also for measurements that are highly sensitive to the surface potential such as the energy distribution of the secondaries. It should also be useful in cases where bombardment damage is a serious consideration, as with the alkali halides.

PART II: ESTABLISHING THE SURFACE POTENTIAL

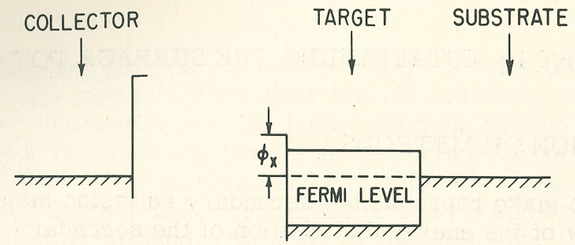
DESCRIPTION OF METHODS

To make reproducible secondary emission measurements, particularly of the energy distribution of the secondaries, the target must be reliably returned to the same potential before each measurement. Several methods of accomplishing this have been used by other workers.[2-9] In this section three methods are examined and compared.

Method 1 - In the steady state an insulator undergoing electron bombardment will assume a potential such that the net current flow to the target surface is zero. If initially the yield is greater than unity, the insulator surface charges positively with respect to the collector by an amount determined by the energy distribution of the secondaries and target resistivity. This results in the target surface potential being established with respect to a chosen collector potential.

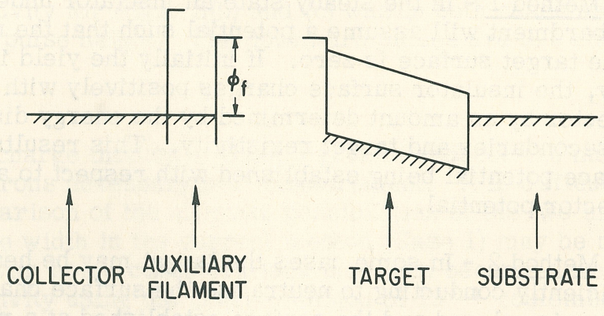
Method 2 - In some cases the target may be heated to become sufficiently conducting to neutralize the surface charge. The charge is relaxed and the surface established at a reference potential with respect to the target substrate. The Fermi level of the target is aligned with the Fermi level of the substrate. Figure 3(a) indicates a simplified possible energy-band diagram for this condition showing the target surface potential with respect to the collector surface and target substrate.

Method 3 - If the target surface is charged slightly positive with respect to the surface potential of a nearby thermionic electron emitter (auxiliary filament of Fig. 1), electrons from the thermionic emitter are attracted to the target surface and establish a reference potential. The electrons that strike the target have sufficiently low energy that the secondary emission ratio is less than unity. The electrons are collected until the target surface potential reaches a value determined by the potential of the auxiliary emitter, energy distribution of the thermionic electrons and target resistivity. Assuming all of the thermionic electrons to be emitted with zero energy, the target surface potential for a perfect insulator is brought to that of the most negative part of the thermionic emitter. A simplified possible energy band configuration is shown in Fig. 3(b) where the effects of internal space-charge in the target have been neglected. As shown in Fig. 3(b) the work function of the secondary electron collector and auxiliary filament are not necessarily the same.



(a)

(a) Establishment of potential of crystal by heating (Method 2).



(b)

(b) Establishment of potential of crystal by very low energy electron bombardment (Method 3).

Fig. 3 Simplified possible energy band configurations.

EXPERIMENTAL COMPARISON OF METHODS

The suitability of the methods described previously for establishing surface potentials has been investigated by measuring the secondary electron yield as a function of the collector potential. In the retarding potential region, the yield is quite sensitive to the potential of the target surface, and thus enables a comparison of the foregoing methods to be made.

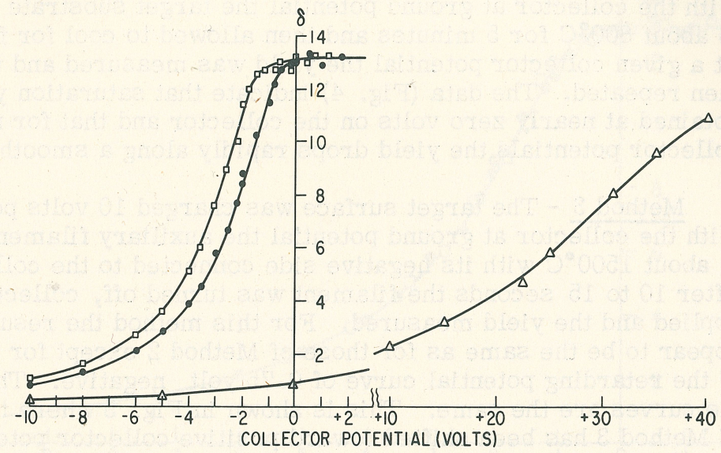


Fig. 4 Retarding potential curves for three methods of establishing the target surface potential. Open triangles refer to stabilizing to the collector potential by bombardment (Method 1). Solid circles refer to stabilizing by heating (Method 2). Open squares refer to stabilizing by very low energy electron bombardment (Method 3). No corrections have been made for contact potentials.

Experiments have been conducted on single crystals of MgO at various bombarding energies. Typical results are shown in Fig. 4. The curves are labeled with regard to Methods 1, 2 and 3 (see caption), and were obtained at 1200 ev primary energy.

Method 1 - The target was charged 10 volts positive. With the collector at ground potential the target surface was bombarded until unity yield was obtained. After applying the chosen collector potential the yield was measured. Results are presented in Fig. 4. Saturation yield was obtained at a positive collector potential of 75 volts although not shown in the figure, and variations in yield occurred for collector potentials up to this value. The unattainability of saturation yield even for some large positive collector potentials has been attributed by Johnson and McKay[9] to patch fields on the target surface.

Method 2 - The target surface was charged 10 volts positive. With the collector at ground potential the target substrate was heated to about 800°C for 5 minutes and then allowed to cool for five minutes. At a given collector potential the yield was measured and the procedure then repeated. The data (Fig. 4) indicate that saturation yield is obtained at nearly zero volts on the collector and that for negative collector potentials the yield drops rapidly along a smooth curve.

Method 3 - The target surface was charged 10 volts positive. With the collector at ground potential the auxiliary filament was heated to about 1500°C with its negative side connected to the collector. After 10 to 15 seconds the filament was turned off, collector potential applied and the yield measured. For this method the results (Fig. 4) appear to be the same as for those of Method 2 except for a shift of the retarding potential curve of 0.75 volt negative. The shapes of the curves are the same. This is shown in Fig. 5 where the curve of Method 3 has been shifted toward positive collector potentials by 0.75 volt.

An explanation for the shift in the retarding potential curves for Methods 2 and 3 is apparent, if one assumes the simplified energy band configuration of Fig. 3. The shift arises from a change in the target surface potential by an amount $\theta_f - \theta_x$ with respect to the collector (Fig. 3). If the work function of the auxiliary filament θ_f is known, the target work function can be determined from the relation $\theta_x = \theta_f + \Delta V$. ΔV is the position of the retarding potential curve obtained by Method 3 with respect to that of Method 2. Using the curves of Fig. 4 and taking 4.30 ev as the value of θ_f for the auxiliary tantalum filament, ΔV is -.75 volt and the work function for this crystal would appear to be 3.55 ev.

CONCLUSIONS

Each of the three methods of establishing the target surface potential possesses merits and limitations. Stabilizing the target near the collector potential by electron bombardment (Method 1) appears to be useful for measurements of the total yield using large values of collecting potential. Measurements can be made rapidly, and with little additional instrumentation. The method appears to be unsatisfactory for retarding potential measurements.

The heating method (Method 2) has been employed by Johnson and McKay[9] and by the authors for measurements on MgO single crystals. Reproducible measurements have been obtained for total yield and energy distribution of the secondaries. Disadvantages of the method include the relatively long measurement times due to heating and cooling of the target,

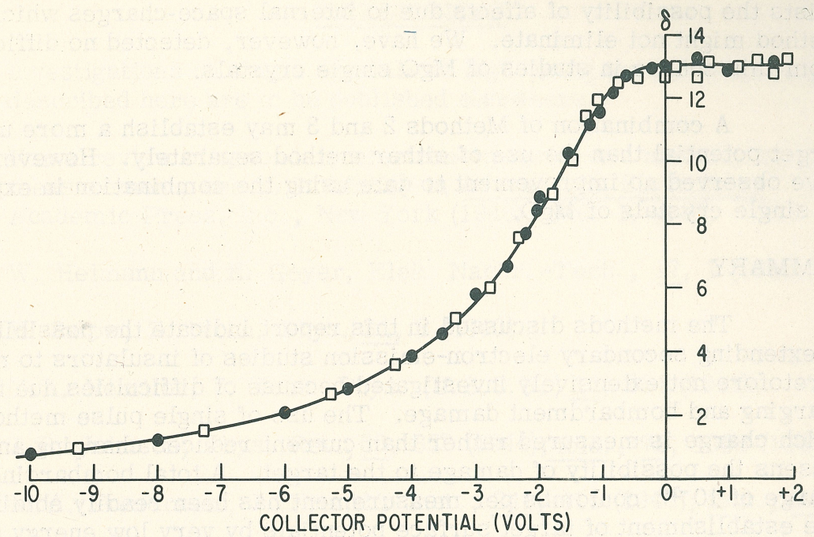


Fig. 5 Comparison of shapes of retarding potential curves from Fig. 4. Solid circles refer to stabilizing the surface potential by heating (Method 2). Open squares refer to stabilizing the surface potential by very low energy electron bombardment (Method 3). The latter curve has been shifted 0.75 volt to the right to facilitate comparison of the shapes of the curves.

and the possibility of changing the target structure and surface conditions. Reliance on volume conductivity to establish the surface potential may not result in the highest degree of uniformity of potential across the target surface.[13] The method is limited to those insulators that can be heated to obtain conductivity and cooled without causing changes in the crystal that affect the secondary emission process.

Method 3 with the auxiliary filament has given very satisfactory results in the determination of total yield and energy distribution of the secondaries from single crystals of MgO. The time required for measurements is considerably shorter than that required when the heat discharge scheme is employed. The method overcomes the disadvantages of possible changes to the target due to heating. There

exists the possibility of effects due to internal space-charges which this method might not eliminate. We have, however, detected no difficulties from this source in studies of MgO single crystals.

A combination of Methods 2 and 3 may establish a more uniform target potential than the use of either method separately. However, we have observed no improvement to date using the combination in experiments on single crystals of MgO.

SUMMARY

The methods discussed in this report indicate the possibility of extending secondary electron-emission studies of insulators to materials heretofore not extensively investigated because of difficulties due to charging and bombardment damage. The use of single pulse methods in which charge is measured rather than current reduces charging and lessens the possibility of damage to the target. A total bombarding charge of 10^{-14} coulombs per measurement has been readily obtained. The establishment of target surface potentials by very low energy electrons offers a rapid method of producing uniform surface potentials for both total yield and energy distribution measurements.

ACKNOWLEDGMENTS

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TITLE

Pulse Measurement Techniques for the Study of Secondary Electron-Emission Properties of Insulators

ABSTRACT

Single pulse measurement methods and surface potential stabilization methods for secondary electron-emission studies of insulators are discussed. The possibility is indicated of extending secondary electron-emission studies of insulators to materials as yet not extensively investigated because of difficulties due to charging and bombardment damage. The advantages in higher sensitivity of measuring charge rather than current are demonstrated. A total bombarding charge of 10^{-14} coulombs per measurement has been readily obtained. Three techniques for returning the insulator to the original surface potential after each measurement are compared. The heating method and the low energy bombardment method are found to agree to within the experimental error in studies on single crystals of MgO.

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~~CONCLUSIONS~~

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INFORMATION PREPARED FOR:

SECTION: Applied Physics

DEPARTMENT: Electron Physics Research